

(Ten Minutes of) Tau Tagging

April 4, 2014: BNL Energy Frontier Workshop

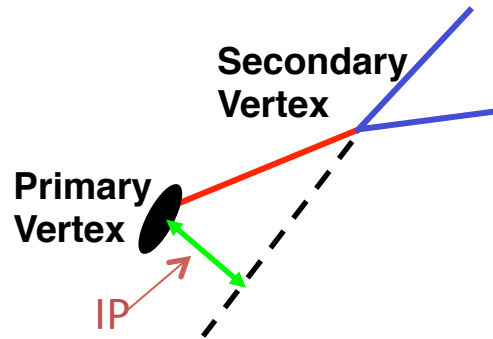


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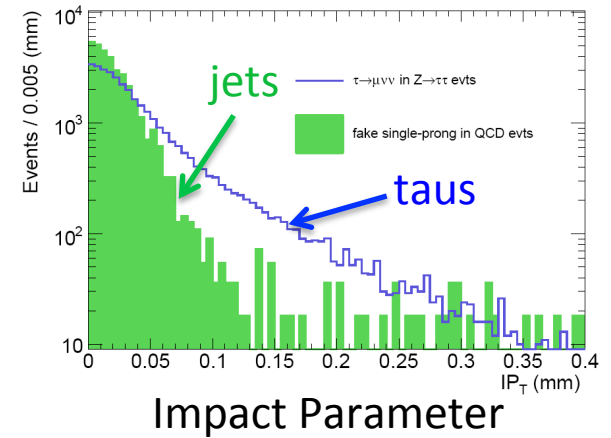
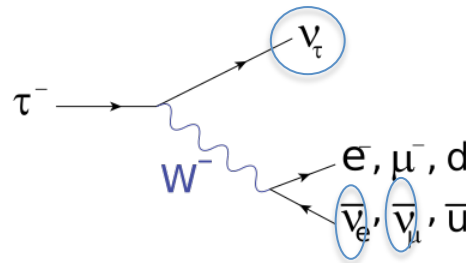


Taus

Lifetime: 10^{-13} s



Missing energy in decay



Channel	Dominant Decay Mode	BR[%]
$e^- \bar{\nu} \nu$	$e^- \bar{\nu}_e \nu_\tau$	$17.82 \pm .04$
$\mu^- \bar{\nu} \nu$	$\mu^- \bar{\nu}_\mu \nu_\tau$	$17.39 \pm .04$
$h^- \nu$	$\pi^- \nu_\tau$	$11.61 \pm .06$
$h^- \pi^0 \nu$	$\rho^- \nu_\tau \rightarrow \pi^- \pi^0 \nu_\tau$	$25.94 \pm .09$
$h^- \pi^0 \pi^0 (\pi^0) \nu$	$a_1^- \nu_\tau \rightarrow \pi^- \pi^0 \pi^0 \nu_\tau$	$10.85 \pm .11$
$h^- h^- h^+ (\pi^0) \nu$	$a_1^- \nu_\tau \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$	$14.56 \pm .07$

Colliding Fundamental Particles

VS.

Colliding Hadrons



Snapshot of results from 2008 BaBar paper, just to illustrate the different world of physics in the two environments . .

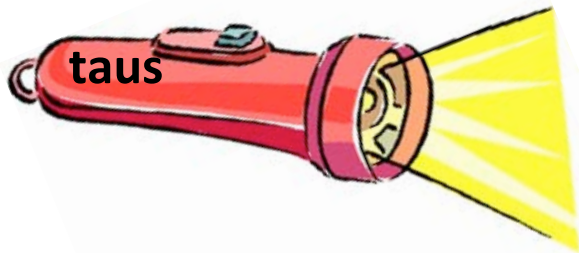
Decay Mode	World Average	BABAR Measurement
$\tau^- \rightarrow K^- \pi^0 \nu_\tau$	$(4.54 \pm 0.30) \times 10^{-3}$ (PDG Avg. [12])	$(4.16 \pm 0.03 \pm 0.18) \times 10^{-3}$
$\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$	$(9.02 \pm 0.08) \times 10^{-2}$ (PDG Fit. [12])	$(8.83 \pm 0.01 \pm 0.13) \times 10^{-2}$
$\tau^- \rightarrow K^- \pi^- \pi^+ \nu_\tau$	$(3.33 \pm 0.35) \times 10^{-2}$ (PDG Fit. [12])	$(2.73 \pm 0.02 \pm 0.09) \times 10^{-3}$
$\tau^- \rightarrow K^- \pi^- K^+ \nu_\tau$	$(1.53 \pm 0.10) \times 10^{-2}$ (PDG Fit. [12])	$(1.346 \pm 0.010 \pm 0.036) \times 10^{-3}$
$\tau^- \rightarrow K^- K^- K^+ \nu_\tau$	$< 3.7 \times 10^{-5} CL = 90\%$ [12]	$(1.58 \pm 0.13 \pm 0.12) \times 10^{-5}$
$\tau^- \rightarrow \phi \pi^- \nu_\tau$	$< 2.0 \times 10^{-4} CL = 90\%$ [12]	$(3.42 \pm 0.55 \pm 0.25) \times 10^{-5}$
$\tau^- \rightarrow \phi K^- \nu_\tau$	$(4.06 \pm 0.25 \pm 26) \times 10^{-2}$ [13]	$(3.39 \pm 0.20 \pm 0.28) \times 10^{-5}$

Is this likely a tau that decayed semi-hadronically ?

and not an
electron
muon
or jet?

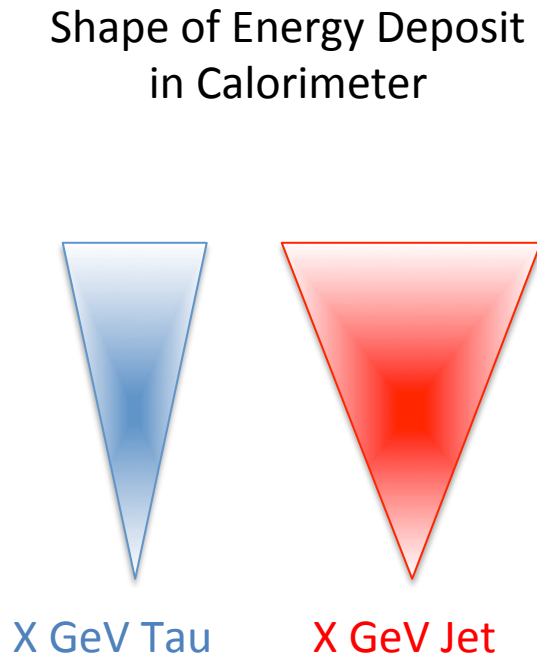


What kind of physics can I do with it?

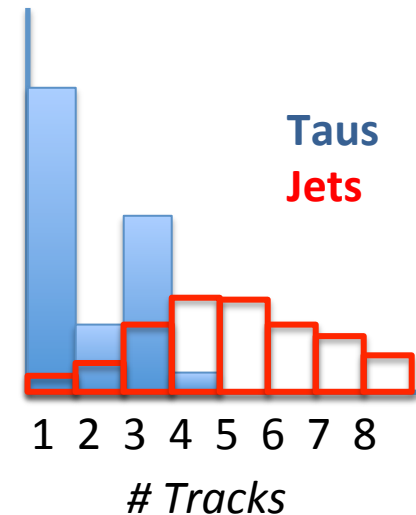


Hey, I got a tau!
Access Polarization
Hunt for Rare Decays

Tau vs. Jet Discrimination



Track Multiplicity



ATLAS: Mainly Boosted Decision Trees

CMS: Classifiers based on Particle Flow tau decay constituents

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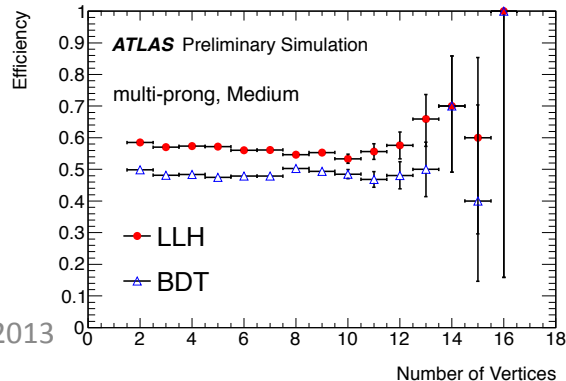
ATLAS Identification Variables

Hadronic Radius: weighted shower width
 Calorimetric Radius: weighted shower width
 Track Radius: weighted track width
 Leading Track Momentum Fraction
 Fraction of Energy in Core
 Electromagnetic Fraction
 Calorimeter Cluster Mass
 Track System Mass
 Transverse Flight Path Significance of 2nd Vertex
 Isolation
 Leading Track Impact Parameter Significance

...

[ATLAS-CONF-2012-142](#)

Stability with Pile-up (2011)



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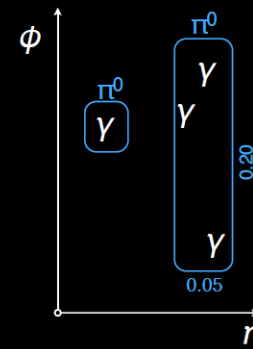
CMS classifiers

Hadrons Plus Strips Algorithm

build signal components combinatorially

cluster gammas into π^0
 candidates using η - ϕ strips

build all possible taus
 that have a 'tau-like' multiplicity
 from the seed jet



π^+
 $\pi^+ \pi^0$
 $\pi^+ \pi^+ \pi^-$

tau that is 'most isolated'
 with compatible m_{vis}
 is the final tau candidate
 associated to the seed jet

Tau Neural Classifier

a neural network for each decay mode

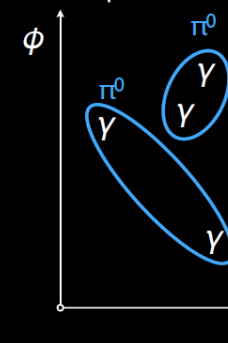
cluster gammas into π^0
 candidates by combinatoric
 pairs compatible with m_{π^0}

signal objects are defined
 using shrinking cone

depending on decay mode

π^+
 $\pi^+ \pi^0$
 $\pi^+ \pi^0 \pi^0$
 $\pi^+ \pi^+ \pi^-$
 $\pi^+ \pi^+ \pi^- \pi^0$

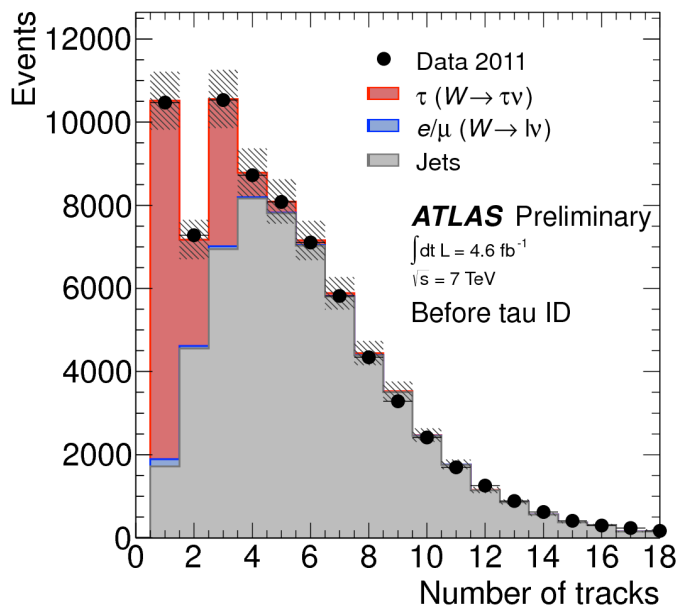
a different neural network
 is applied!



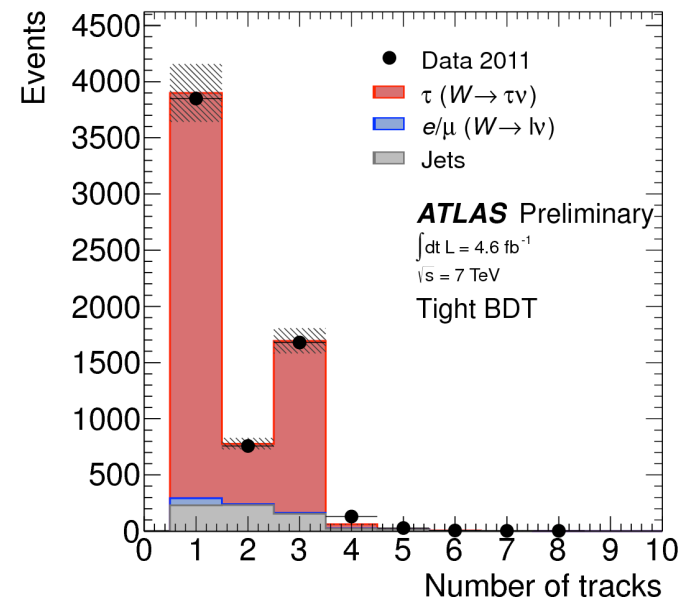
Performance Examples:

$W \rightarrow \tau \nu$ selection

BEFORE “tight” tau Identification
(tuned for 30% signal efficiency)



AFTER “tight” tau Identification
(tuned for 30% signal efficiency)



A jet is not a jet is not a jet

leading jets, sub-leading jets, etc.

pile-up influencing jet clustering

track multiplicity

jet transverse momentum

quark-initiated jets vs. gluon-initiated jets

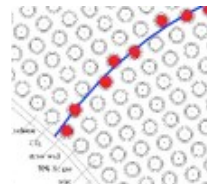
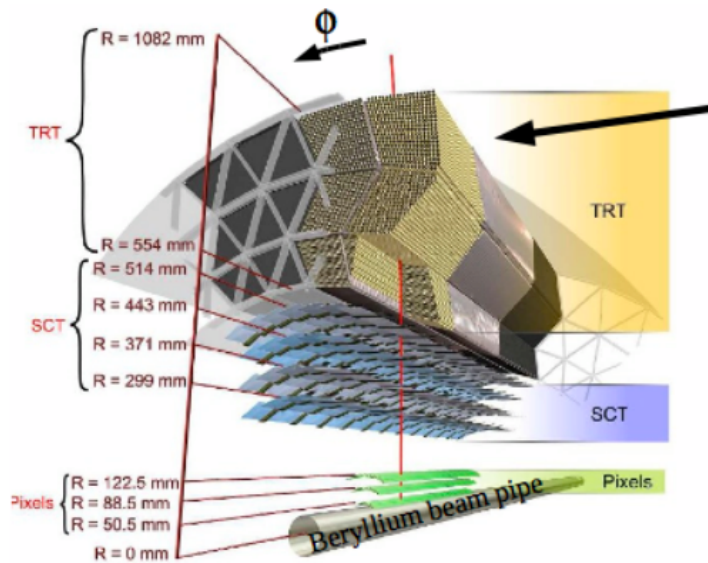
Many of these topics have been explored,
but we have room for much more sophistication moving forward!

Tau vs. Electron Discrimination

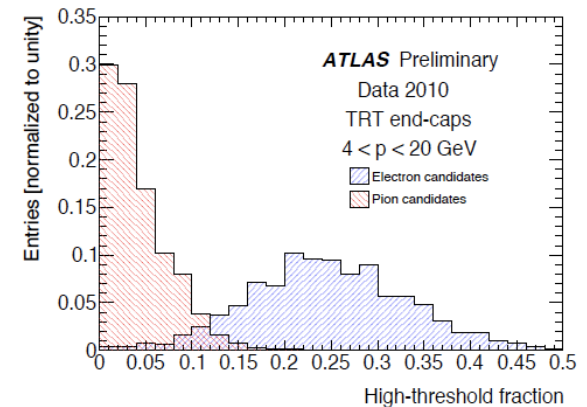
a 1-track tau can look quite a bit like an electron

At ATLAS, a high fraction of electrons are reconstructed as tau candidates, and pass the identification stage that was designed to veto jets

Particle ID capabilities in the tracker is hugely helpful!



Pion – Electron Separation



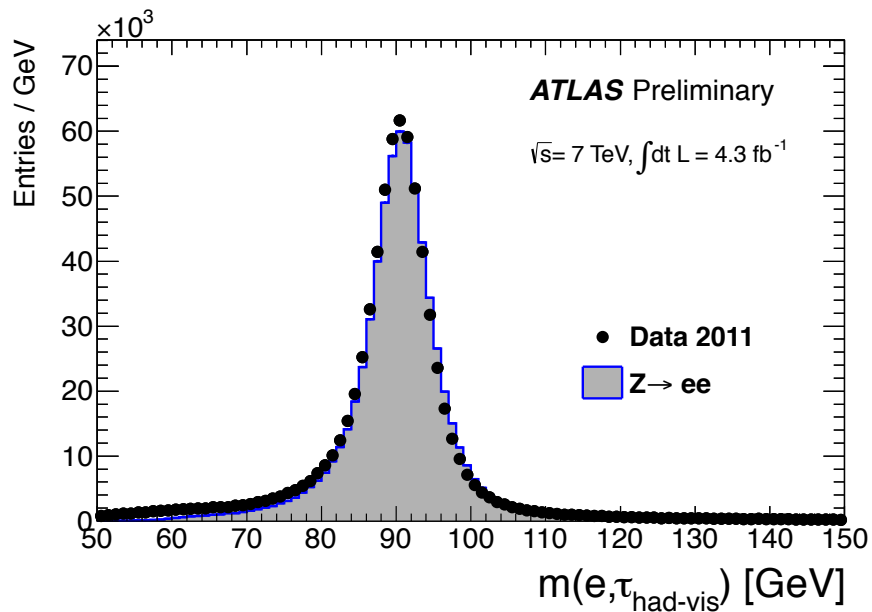
Luckily, looking forward, pions and electrons behave differently in the calorimeters as well!

Electron Veto Performance:

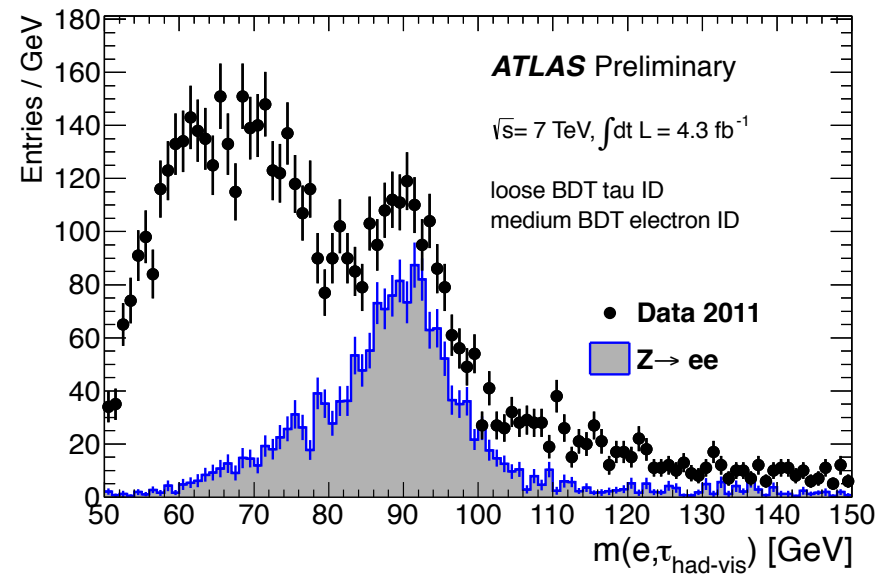
$Z \rightarrow ee$ events

Tight requirement on one electron, require tau candidate in event, no background subtraction in plots below.

BEFORE tau ID and electron veto

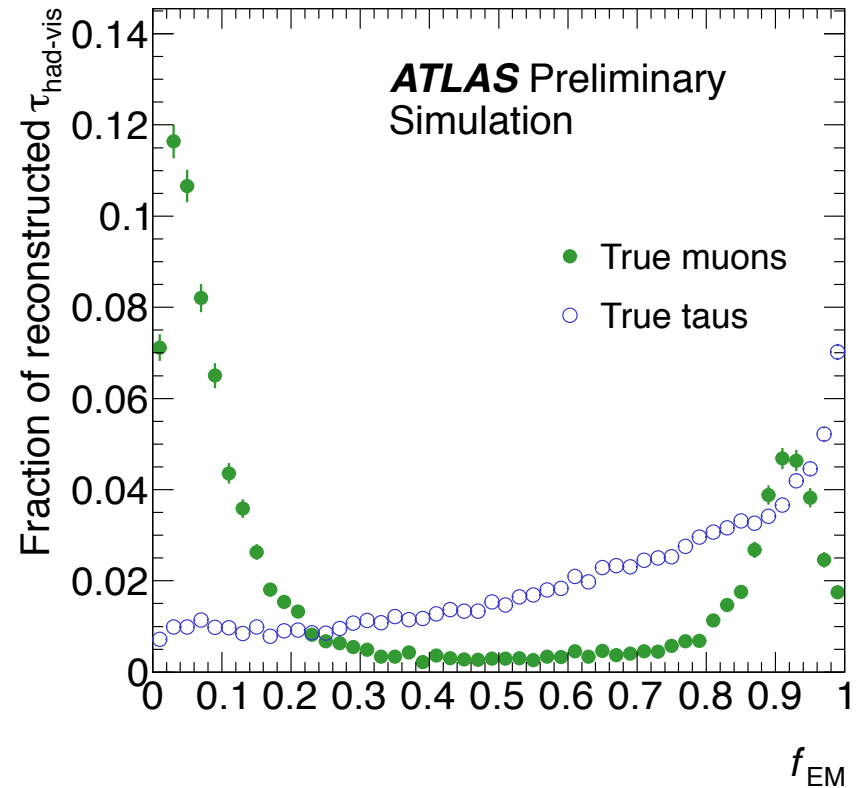


AFTER tau ID and electron veto



Tau vs. Muon Discrimination

Muon vs. Tau separation is not typically a concern, assuming EM and HAD calorimeters have fine enough granularity.

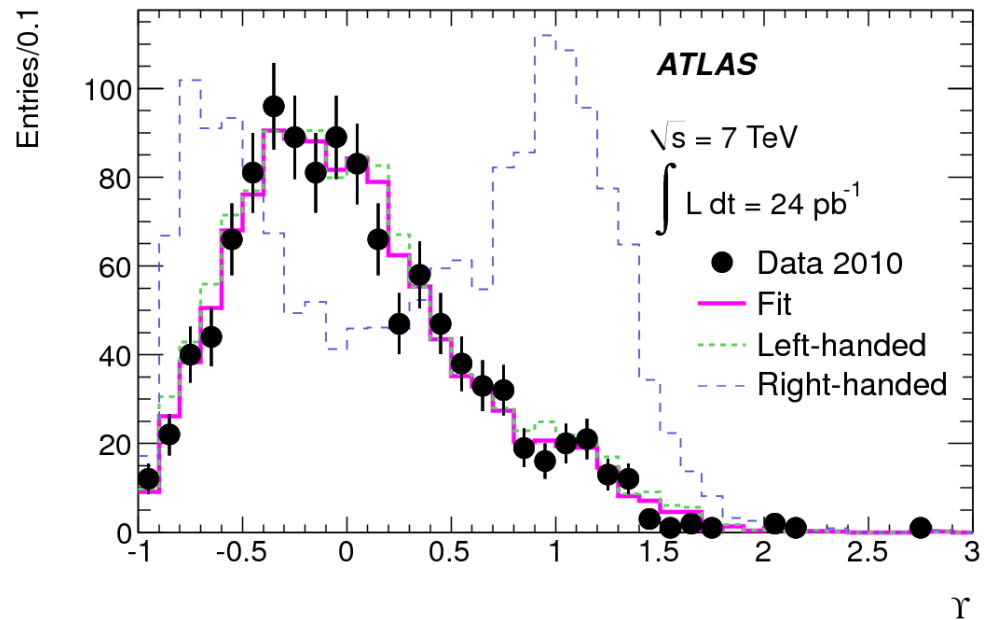


Fraction of transverse energy of
tau candidate deposited in
electromagnetic calorimeter

On Not Underestimating the Power of Statistics

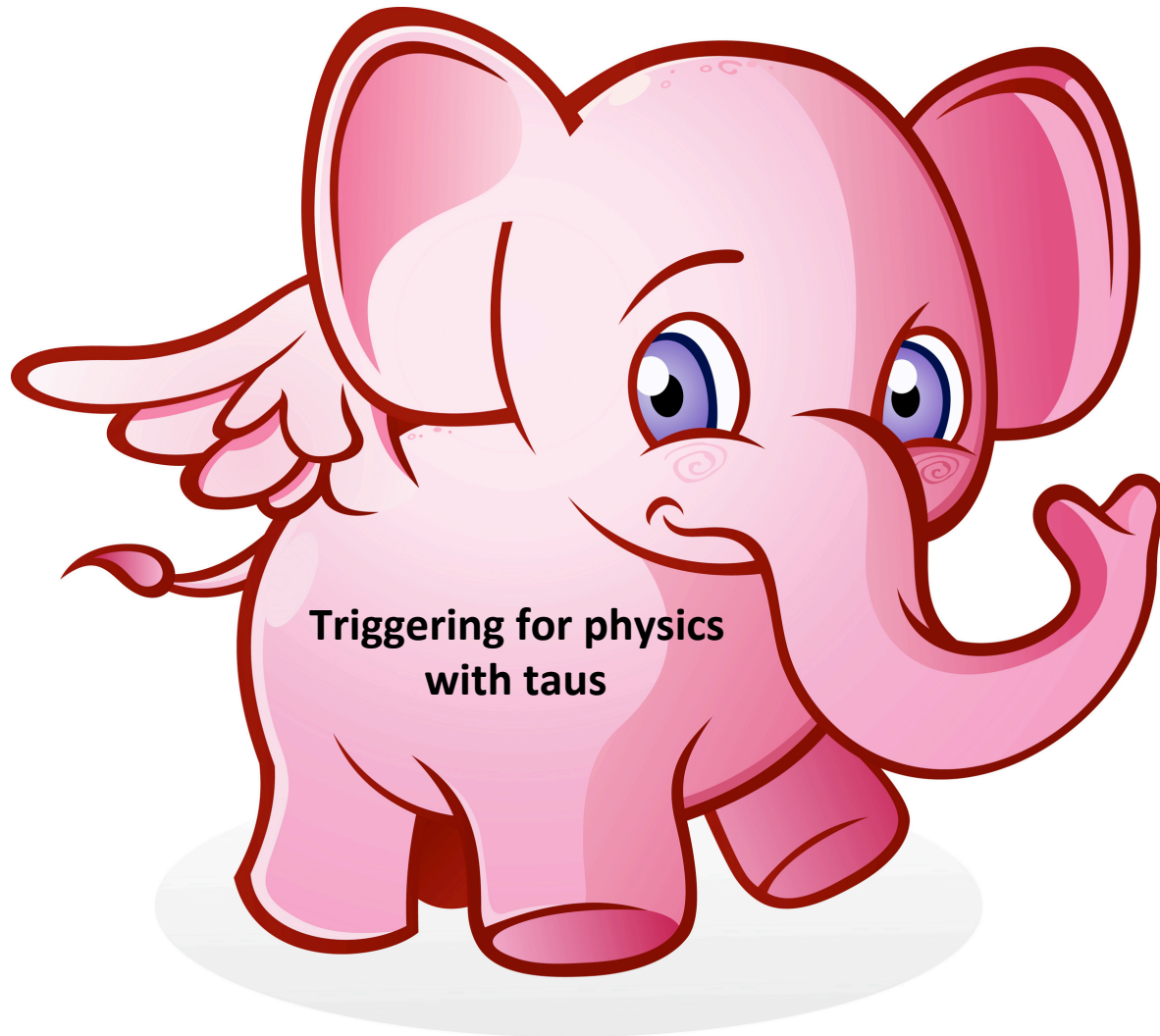
Measurements that rely on tau polarization CAN be done at hadron colliders

Process	P_τ Prediction
$W^\pm \rightarrow \tau \nu$	-1
$H^\pm \rightarrow \tau \nu$	+1
$Z \rightarrow \tau \tau$	≈ -0.15
$H \rightarrow \tau \tau$	0



$$P_\tau = -1.06 \pm 0.04 (stat) {}^{+0.05}_{-0.07} (syst)$$

And the elephant in the room



Summary: What We Want for Tau Tagging

- Good Tracking (particle ID a plus here!)
- High Granularity EM and HAD Calorimeter
- Knowing initial conditions, like energy of colliding particles/partons, facilitates measurements with taus
- Not knowing initial conditions provides complications, but doesn't take you out of the game in a world of high statistics
- Particle Discrimination (K , π , π^0) is required for precision measurements